ROORKEE TREATISE ON CIVIL ENGINEERING.

SECTION III.

CARPENTRY.

SEVENTH EDITION (REPRINT).

REVISED BY

Lieut.-Col. A. M. BRANDRETH, R.E.,

Late Principal, Thomason Civil Engineering College, Roorkee.

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PREFACE

TO THE

Roorkee Treatise on Civil Engineering in India.

The Roorkee Treatise was originally compiled by Lieut.-Col. J. G. Medley, R. E., in 1866 and issued in two volumes.

The Treatise grew out of the various College Manuals, dealing for the most part with subjects which required special treatment to suit the climate and methods used in India, and has been constantly revised and re-written. It is found advisable now to publish the Treatise in separate sections, so that each Section can be re-written or revised and brought up to date whenever opportunity occurs, to keep pace with modern methods and discoveries.

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,,	VII*a*.	Chapter on Steel Bridges		1925.
,,	VIII.	Roads. ...	...	In Press.
,,	IX.	Railways ...	...	1925.
,,	X.	Irrigation Works	Vol I.	1924.
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ROORKEE TREATISE.

SECTION III.—CARPENTRY.

CHAPTER I.

JOINTS.

A preliminary Chapter on this subject has already been given in Section I on Building Materials, but the substance of it will be repeated here.

For description of the Carpenter's tools and his methods of working with them, students are referred to Mitchell's Lessons in Carpentry Workshop Practice, which also is a College Text-book, if they are not already acquainted with these details. In this Section it is assumed that they know how the wood is reduced to the various shapes shown to be required.

Although the use of large timbers in buildings of any sort has been almost entirely superseded by iron, especially in India where timber is both expensive and peculiarly subject to decay, the principles of jointing and framing are the same for small as for large structures, and should be carefully studied.

2. *Joints.*—As a first general principle, it may be safely laid down that these should be as simple as possible, not only to save useless labour in construction, but also because every separate face or angle forms a lodgment for dust and vermin, and thus hastens decay. The elaborate indented forms given in Tredgold and other ancient treatises on Carpentry, were possibly necessary when enormous structures had to be joined together with no aid from iron plates and bolts, but these are now universally adopted, and perform all the offices of the indentations, etc., of the old joints, so that they should never be put in now-a-days, unless the reason for them can be shown.

3. Therefore, as a general rule, joints should be made as simple as possible, just plain butt ends cut square across the

length to take the compression, with a small mortise and tenon perhaps to avoid lateral displacement by accidental shock, and simple suitable iron plates screwed on, or stouter plates of bar iron bolted on, to resist the tension strains.

4. When two pieces of wood are joined so as to make one longer straight piece, the joint is either called a fished joint or a scarf. It is called fished when the connection is made by additional pieces of either wood or iron, laid on outside, and secured by bands or bolts, as in Plate I *Figs.* 1, 2. The plates being either on all four sides, or only on two, and no attempt made to gain any strength by joining the two pieces of wood.

5. A scarf on the contrary, though almost always aided by fish-plates, is a join between the two pieces of wood more or less self-sustained. Plate I *Fig.* 3 shows a form of scarf. Here the two pieces are cut to fit into each other, and forced up into close contact by driving the keys k, which are slightly wedge-shaped.

6. Now the goodness of the joint of course depends on its suitability to resist the strain it is subjected to. A joint such as *Figs.* 1, 2, 3, should strictly only be subjected to direct pressure, as in a pillar carrying a weight, but it may also be required to resist tension, that is, the forces may tend to pull the two pieces apart, and it is sometimes by clumsy construction, but should never be called on to resist transverse strain, as occurs in a horizontal beam carrying a load.

7. Now for the first and second of these strains the post as a whole is calculated large enough in section to support the weight without crushing or tearing asunder; that is, it is known from experiment that a square inch of cross section of the particular wood can safely withstand a certain strain, and the load to be carried is divided by this weight to give the number of square inches necessary for the section of the post. In *Figs.* 1 and 2 the whole section fits fairly, and is available to resist the crushing. In *Fig.* 3 there is the same area of course, but it is cut up into three or four smaller faces, and if the carpentry is not exact, or the wood shrinks unevenly, the whole weight may come on one face and crush it, and then on the next, and so on in succession. There is no advantage that can be claimed for *Fig.* 3 except neatness, and the cost of construction is of course greater.

8. For the second strain tension, *Fig.* 3 has a certain advantage, one-third of the section at aa is available to resist the extension. But the joint may fail by separation of the wood along the dotted lines bc. or b' c', which must be made a considerable length to give the requisite strength, as in most woods the

strength against sliding off along the grain in this way is but slight. The remaining two-thirds of the strength required to resist the tension must be supplied by iron plates and bolts, and the plates must be bolted with a sufficient number of bolts in the solid timber beyond the scarf, and are therefore very long and expensive, while if the shorter plates in *Fig.* 2 are made one-third stronger, that joint is as good as *Fig.* 3.

9. For transverse strain no joint can be complete without the help of a fish-plate below, as will be seen when beams are treated of further on, but *Fig.* 3 with a plate on lower side, is as good as any that can be made, but again no way better than *Fig.* 2.

10. Although no lateral strain should come on the piece in a properly designed frame, it may perhaps be said that No. 2 is deficient in lateral stiffness, and this is the reason that the joint is usually made as No. 4. The only objection to this is the extra length of plates required. But this joint, with perhaps a very short mortise and tenon joint at the end of each half (*see Fig.* 5.) has every advantage that the most complicated scarf can have, and is cheaper and easier to fit and consequently less liable to decay.

11. *Angle Joints.*—For joints where the pieces meet at an angle, as for example all the joints of the simple truss, Plate II *Fig.* 6, exactly the same principles apply. The wood should resist the compression strain only, and this by plain square butt joints, and all tension should be provided for by suitable iron work, lateral displacement being prevented by the smallest possible mortise and tenon. These facts are much forgotten in practice, not only are elaborate wooden joints worked out, but the ironwork given is in many cases most elaborate and expensive, and yet quite unsuited to the work it has to do.

12. The study of an example will make all the foregoing clear. In an ordinary King-post truss, as *Fig.* 6, the various pieces are in compression or tension as shown by the thick and thin lines, and the figures show the stresses in pounds in the ordinary case of the tiled roof of a barrack, of say 20 feet span and double tile roof. The stresses at the several joints are shown by the arrows in *Fig.* 7, which also shows an exaggerated figure of a properly designed wooden truss. There would be slight mortises and tenons at each joint to prevent the pieces moving laterally, but no ironwork would be needed at all.

13. At the joints AA′ the thrust down the rafter is fitted fairly on the projection on the tie-beam, and the equal strains by the two rafters are counteracted by the tie-beam, which is made strong enough to resist the tension. But here it is at

once evident that a great deal of wood has been cut away to waste from the tie-beam, which must originally have been the full depth it is now at the ends all along its length, and again the joint is liable to fail by the projection on the tie-beam separating off along the line *aa*. Hence, even if an iron tie-rod is not used, it is usual to make the tie-beam only enough to resist the tension and secure the foot of the rafter to it by a strap and bolt as shown in *Fig.* 8.

14. All calculation or Applied Mechanics has been relegated to the third Volume of the Treatise, but the reasoning on joints will not be plain without an example, and therefore that for this joint follows in detail. Only the results of the calculation will be given.

The first is the section necessary for the rafter under compression. As the stress is 12,000 lbs., and the safe stress per square inch is 1,200, this would be 10 inches, but the length of the piece AB enters into the calculation, and makes the section 20 inches to be secure against bending as well as crushing. Thus it is only necessary that half the section should be fair cut to take the crushing stress, and the wooden joint may be even as *Fig.* 7.

15. Next this crushing strain may be represented by AC in *Fig.* 9, and can be resolved into AW and AT, of which AW will represent the downward pressure on the tie-beam, which is supported by the wall, and AT has to be provided for by the tie-beam. This is the 10,810 lbs. in *Fig.* 6. The section of wood needed to withstand this will be 9 square inches, and the tie-beam must be nowhere less than this, and also if the end of the tie-beam along *aa*, *Fig.* 7, is made long enough so that 10,810 lbs. will not push it off, then the wooden joint *Fig.* 7 will be quite safe.

16. The principles on which iron straps should be adjusted can be shortly explained by an example, but the Resolution of Forces must be brought in. Thus, the sloping rafter exerts a force represented by AR, *Fig.* 10 ; say 12,000 lbs., the only direction of force that the tie-beam can resist, if it has as we suppose no indentation, is perpendicular to its surface, *i.e.*, vertically downwards in direction AW. Another resistance must be introduced by the iron strap, which combined with that in direction WA will resist AR. The least pair of forces are evidently HA and DA, but as the strap can never be put on horizontally, some convenient direction, as near horizontal as possible as TA is selected, and the forces then become QA and EA, and, in the case given QA would be 12,000 so that the strap must be made equal to resist that strain.

17. Sometimes for convenience of fitting the strap it is put on square with the rafter, as *Fig.* 11. In this case the same principle applies; the parallelogram with one vertical side, one in direction perpendicular to rafter, or in direction of strap, must be made on diagonal AR, and whatever relation the side parallel to the strap bears to AR, will give the strain to which the strap will be subjected. It will be observed that a much stronger strap is required in this case.

18. The upper end of the rafter where it butts on the King-post may be taken as an exactly similar case. Turn the figure a quarter circle, so that the King-post becomes horizontal, and the case is identical. Hence the iron strap in this case should be as nearly parallel to the King-post as possible, say as in Plate III *Fig.* 12, not as in *Figs.* 13 and 14 as often given.

19. The struts again at their lower ends are precisely similar cases, but here, as a convenient construction, advantage is taken of the tie-beam, *see Fig.* 15 as a stop, and it is secured to the King-post by the strap passing round it and bolted at its open end to the King-post, a similar stop might often be found a simple arrangement at the head of the truss, as in *Fig.* 16.

20. The joint at the top of the strut is really the same; here there is the direct weight of the roof as W, *see Fig.* 17 which causes the strut to push the rafter up, if one may say so, with a force of 4,000 lbs., and this is really a similar case, and the strap, if one is used, should resist the tendency to slide down the rafter represented by BT, and therefore should be placed as *Fig.* 17. This force is, however, but a small one, and is generally considered sufficiently resisted by the mortise and tenon, or sometimes a cleat is given as *Fig.* 18.

21. Thus for any joint, where iron is used, it should be distinctly understood what it is used for. If it is to prevent the pieces dropping apart when being hoisted up, which is the only office that the strap at apex of truss in the form often seen as *Fig.* 14, can really perform, a light plate and screws will do all that is needed. If it is to resist the thrust of the sloping rafter, the strap must be as nearly parallel as possible to the tie-beam or similar piece.

22. Sometimes in simple cases a compromise may be effected, and the one form do both offices, but then it should be the plate, which can do it by its stiffness as *Fig.* 19.

23. It must be remembered that in all these cases straps can fail or bolts shear off at any point where they are weak, and it is no use to have a broad strap, and then weaken it by the bolt hole, as *Fig.* 20, so that only half the breadth remains at that

point, the strap must be made as *Fig.* 21. And again, the bolt must be as strong as the strap, or if this cannot be done with one bolt, more must be given. But with the maxim that the strength of a chain is that of its weakest link, and the above explanation as to the resolution of forces, the student should be able to design any joint, and there is no advantage in multiplying examples by considering the Queen-post truss or other style in detail.

CHAPTER II.

FLAT ROOFS, FLOORS, BUILT BEAMS.

24. Flat Roofs.—For these, as commonly built in India, there is little carpentry required, the room or space to be covered is crossed by beams of rectangular section at certain intervals, usually from 3 to 6 feet apart. These again are crossed by timbers of smaller cross section, called burgahs, their spacing apart and scantling being determined by the nature of the covering. Indeed it is this that really commences the calculation. If for instance the ordinary terraced roof, carried on bricks, is to be built, the burgahs must not be further apart than a brick can span, say 12 inches from centre to centre; again, the brick not being very even or square at its ends cannot be given less than 1 inch bearing, which fixes the least breadth possible at 2 inches, and the proper depth corresponding to this is about 3 inches. But as $2'' \times 3''$ is rather a flimsy sort of scantling in any but the straightest grained wood, burgahs are seldom made less than $2\frac{1}{2}'' \times 3\frac{1}{2}''$, and $3'' \times 4''$ is better. The length will then depend on the greatest length of this scantling that will stiffly carry one foot breadth of the roof material, whatever it is, and this length fixes the spacing apart of the beams, or at all events is the consideration which leads to it.

25. In the case of a verandah or any narrow room, it may be more convenient to make the burgahs, or karis as they are then called, stretch right across, and have no beams. The scantling will then be calculated sufficient to carry one foot breadth of roof across the breadth of the verandah.

26. The *exact* spacing of the beams in a room will depend on its length, that it may be divided into even spaces, and often the necessity of avoiding a chimney will alter the whole arrangement first worked out on the question of the economy of wood only.

27. For example, say sál burgahs $2\frac{1}{2}'' \times 3\frac{1}{2}''$, placed one foot apart, will carry a roof 100 lbs. to the foot, 6 feet broad, *i.e.*, the beams may be placed with this interval between them. If the nearest convenient spacing came to be 7 feet centre to centre, the burgahs would have to be made about $3'' \times 4''$. If

again beams large enough in section to carry 6 feet breadth of roof could not be obtained, and the spacing had to be 4 feet, the waste of burgah must be accepted, as smaller scantling than $2\frac{1}{2}'' \times 3\frac{1}{2}''$ is not a working size. The bricks would not have safe bearing, and the pieces would be deficient in stiffness and wear, as the grain of the wood cuts out in very small scantlings.

28. Again, if the room was say, 36 feet long, and there was a chimney in the middle of the long side, spaces of 6 feet would give six spaces or five beams, but the centre one would come right into the flue. Here probably 7 feet 2 inches spacing would be adopted, giving five spaces, or four beams, and so placing them 3 feet from the flue, and the burgahs would be calculated accordingly.

29. If again, the roof covering was different, say terrace supported on slab stones, which spanned 2 feet, this would alter the case, and calculations accordingly. In each case the wood must be carefully calculated and sawn to the requirements, but there is no carpentry so to speak.

30. Floors.—These may of course be made exactly as the roofs just described, allowance being made for the load they have to carry, as well as their own weight, and floors are often so made in houses in the plains of India. But in Europe and in the Hills of India, planked wooden floors are very common, as being much lighter and more suitable in many ways.

31. Tredgold describes three sorts of floors—*single joisted*, *double joisted*, and *framed*. These are respectively shown in Plate IV, *Figs.* 22, 23, 24.

Bridging joist or Single joisted Floors, Fig. 22.—No. 1 is the plan of an apartment: *a a a a* are the walls, *b b* the wall-plates, *c c c c*, etc., the bridging-joists, *d d* part of the flooring boards. The bridging-joists are usually placed from 10 to 12 inches apart: their scantling is dependent on their length, their distance apart, and the weight they have to carry, and may be calculated as in the case of flat roofs.

No. 2 shows an enlarged section through the joists at right angles to their direction: *c c* are the bridging-joists, *d* the edge of one of the flooring-boards, *e e* the side of a ceiling-joist. The ceiling-joists cross the bridging-joists at right angles, as seen at *e e e*, No. 1, and are notched up to them and fastened with nails. Sometimes every third or fourth bridging-joist is made deeper than its fellows, and the ceiling-joists are then fixed to them only. This has the advantages of preventing sound passing so readily, and making the ceiling stand better.

32. When the bearing of single joists exceeds 8 feet, they should be strutted between, to prevent their twisting, and to give

them stiffness. When the bearing exceeds 12 feet, two rows of struts are necessary ; and so on, adding a row of struts for every increase of 4 feet in the bearing.

There are three modes of strutting employed, the first and most simple is to insert a piece of board, nearly of the depth of the joists, between every two joists, so as to form a continuous line across. The struts should fit rather tightly, and are simply nailed to keep them in position. The second mode is to mortise a line of stout pieces into the joists in a continuous line across, but the mortises materially weaken the joists. The third mode is represented in the section No. 2 ; *f f* are double struts, of pieces from 3 to 4 inches wide and $1\frac{1}{2}$ inches thick, crossing each other, and nailed at the crossing to each other and at their ends to the joists. The struts should be cut at their ends to the bevel proper for their inclination. To save the trouble of boring holes for the nails, two slight cuts are made at each end with a wide-set saw, and the strut is nailed through these with clasp-nails. Of the three modes, the last is the best. In No. 1 *f f f* show three lines of struts.

33. Double-joisted floors are shown in *Fig.* 23, 1 and 2. Here the span is too great for single close joists, and therefore beams have to be used, as *a*, but over the beams and the end walls the roofing is exactly like a single-joisted floor. Plate V *Fig.* 24, 1 and 2, shows a *framed floor.* Here large beams A cross the room, and across the spaces between them smaller beams B, B, are framed *i.e.*, their ends are notched into the beams A, *see Fig.* 24, 2, instead of being placed over them, thus keeping the depth of the floor very little greater than that of the large beams A. The joists C, C, crossing B, B, and planking above them are just like a single-joisted floor. They and the ceiling joists are also notched into the beams they rest on to save depth ; of course in all cases where a beam is cut into or notched, allowance must be made for the weakening thereby caused, in designing the scantling of the beam.

34. *Trimmers.*—When some joists would, from their position, run into a fireplace or flues in a wall, it is impossible to give them a bearing there. In the case of the floor, *Fig.* 22, two short timbers, called "trimmers," are introduced—one on each side of the place to be cleared, with one end resting in the wall, and the other *framed into* the third joist from it : into the outer side of these, respectively, the end portions of the two first joists are framed, the intermediate portion being dispensed with. The joist into which the trimmers are framed is called the "trimming-joist," and is made thicker than the others, according to the number of joists dependent on it for support. The hearth rests

on a brick arch turned between the trimming-joist and the wall. Trimming is also resorted to for stair and other openings.

35. The necessity for this framing or notching the ends of the trimmers and joists *into* each other is, that they cannot be placed *on* each other, as the upper surface of all joists and trimmers must be on one level to take the planking fair. It is no doubt a weakness in construction, but unavoidable, and if extra strength in the timbers is allowed may be made quite safe.

36. In laying the boarding, the edges may be tongued and grooved, or merely laid with square edges, but in this case pins, as *Fig.* 25, should be given at intervals. In either case in laying the boards, five or six are made to fit as close as possible, but are not nailed to the joists. The 6th is then raised, and the 7th nailed down a little over the mark of the edge of the 6th. The 5th and 6th or 3rd and 4th are then placed as shown in *Fig.* 26, and when forced down by being weighted, tighten up all the others. In a small room the whole may be done at once with the centre two boards. After being forced tight in this way, the boards can then be nailed down to the joists.

37. Built Beams.—When a beam is required for a larger span than about 22 feet, it has to be made up of pieces, as it is not often that beams of greater length than this can be obtained. It is not often that buildings of greater span than this are covered with flat roofs, but double-storeyed buildings of any breadth must have floors, and these must be made of horizontal beams.

38. To understand the construction to be adopted, it is necessary to consider how a beam carrying a load is strained, and it will be sufficient if it is understood, as shown by the exaggerated fracture in Plate VI *Fig.* 27, that the upper part is crushed together and the lower part pulled asunder. Or a simple truss, as *Fig.* 28, is nothing but a beam, here any one can see that a load W compresses the rafters and stretches the tie-rod, and the same is the case however flat the truss is made, *Fig.* 29, for any load or compression on the rafter.

39. If the beam is made of separate pieces, then it will be evident that the lower portion, which is in tension, must be of connected pieces for the whole length, but the upper portion may be in short lengths, provided they are firmly fixed to the lower portion, so that they cannot slide apart under the pressure. Thus if a sort of fagot, as *Fig.* 30, were composed of upper pieces of short lengths, with their ends in close exact contact, and of lower pieces in continuous lengths, the whole bound together so that sliding of the pieces one on the other was impossible, it would be theoretically a perfectly strong construction.

40. But the same turned upside down would be of little strength, as the bottom half would open out at once under the tension strain, and leave only the top half to stand both strains. And again, even when right way up, if the whole were not fastened firmly together, so that the pieces cannot slide upon each other, the beam would only be a lot of separate weak ones as far as the continuous pieces were concerned, and the disconnected portions in the upper half would be no use at all.

41. A little consideration of the above will fix a clear idea in the Student's mind of the strains in a beam, or girder, or truss under transverse strain, and will make the rule laid down about scarfing for beams in para. 9 clear. The wood can take the strain of compression in the upper half, even though there is a joint, but cannot take the tension in the lower, and so straps are necessary.

42. Built beams of large size are made with regard to these facts. If long pieces of small scantling can be obtained, a beam of large scantling can be built up in fagot form, as shown in *Figs.* 31, 32, 33, which are of course exaggerated in the detail. A slight taper may be given to facilitate driving the bands on tight, but these are old-fashioned constructions, quite superseded by the introduction of iron for the tension members.

43. Trussed beams are only another form of built beam using iron. Several ordinary forms are given, *Figs.* 34, 35. Here the wooden beam acts as the part in compression, and evidently may be made of several short pieces, provided that the possibility of sliding and lateral displacement is provided against. The tension in the lower part is taken up by the iron tie, which is firmly fixed at the ends to the compression part by plates and nuts, as is of course absolutely necessary.

44. But even trussed beams of wood and iron would rarely be adopted now-a-days, unless for some ornamental wooden roof it was necessary to make a beam which could be cased in wood, and look as if it was only wood, or where in houses of several storeys the depth that could be allowed for the flooring was limited.

45. Where appearance or space is no object, trussed beams would be made much deeper, more as *Fig.* 35.

46. Beams can even be made of planks placed side by side breaking joint and keyed together as a whole; but here the tension resistance depends entirely on the keys, and it is but a feeble sort of construction only to be adopted when no other is possible.

47. The iron fastenings of timber, especially if in contact

with oak, rust very rapidly unless properly protected. Amongst the most efficient means of protection are the following :—

I. Boiling in coal-tar, especially if the pieces of iron have first been heated to the temperature of melting lead.

II. Heating the pieces of iron to the temperature of melting lead, and smearing their surfaces while hot, with cold linseed oil, which dries and forms a sort of varnish. This is recommended by Smeaton.

III. Painting with oil-paint, which must be renewed from time to time. The linseed oil process is a good preparation for painting.

IV. Coating with zinc, commonly called galvanizing. This is efficient, provided it is not exposed to acids capable of dissolving the zinc ; but it is destroyed by sulphuric acid in the atmosphere of places where much coal is burned, and by muriatic acid in the neighbourhood of the sea.

CHAPTER III.

FRAMES, PENT ROOFS, PARTITIONS.

48. Frames.—When large spans have to be crossed, trusses, girders, centres, etc., are used, all of which may be called frames. The action of the transverse strain is, of course, exactly the same as before explained for beams, the upper part is compressed, the lower stretched; but as we can construct these frames of any section and shape, advantage is taken of the knowledge gained from the science of Mechanics of the intensity of these stresses at different parts of the frame to build it up with its material arranged where it will best resist these strains. As these laws generally stated are very simple, and are necessary to the understanding of the construction of a frame, they will be given.

49. Taking a plain rectangular girder A*ab*B, supported at its ends, and loaded along the top, Plate VII *Fig.* 36. As we have said before, the upper part, say above NX, is crushed, and lower below NX extended. This plane NX is called the neutral layer, because it is found that the pressure is greatest in *ab*, and the tension in AB, both decreasing till they are nothing at all at NX. It is, therefore, evidently useless to have the section of the girder rectangular, it would be just as strong and much lighter if made as *Fig.* 37, great where strain is great, and small where it is small. But it is also found that if the central part between *ab* and AB is just *stiff* enough, the most advantageous distribution of the material is to crowd it all as far away from the neutral plane as can be, where the strain is greatest, into what are called *flanges*, leaving only just a thin *web* between them stiff enough to keep them apart, as in *Fig.* 38. Much less material will serve with this section than with a plain rectangular one, or even with one like *Fig.* 37.

50. Again, the actual amount or intensity of compression or tension in the flanges of the frame is known to be greatest at the centre of the span, and to gradually decrease towards the ends, and the reverse is the case in the web, *see Fig.* 39, and the strength can be arranged to meet this by increasing the section of the flanges from the extremities towards the

centre, or, as the strength of the girder also depends on its depth, by increasing the depth towards the centre, keeping the flanges the same uniform cross section all through, and the strength of the web can be arranged for by varying its section.

51. By attending to the above considerations, a frame can be made equal to the strain brought on it by the load at each point, and containing no waste material, and thus also as light as possible, which as well as the economy, is a most important point in large frames, as many badly designed ones have difficulty in carrying their own weight alone.

52. The above is only a very general description of the principles involved, and is mathematically loose in several places, but will, it is hoped, make the consideration of frames fairly clear.

53. These frames can be built up of small lengths, generally called *pieces*, none of which would span one-tenth the whole space, and it will be observed the pieces are all made into triangles, as that figure cannot alter in shape, unless one or more of its sides alters in length. Theoretically the loads on the frames should only be put on at the joints, as the meetings of these pieces are called, *i.e.*, A, B, V, in *Fig.* 39, and then the pieces can only be strained by direct compression or tension, not by transverse strain. Also the frame can be and is so arranged, that it needs no stiffness at the joints, each of the pieces might be hinged at the joint without endangering the stability under any load whatever. In *Fig.* 39 the thick lines show pieces in compression, the thin those in tension, and the figures show the strains on each piece when the frame is loaded with 100.

54. Roofs.—*Figs.* 40 to 44 show frames or *trusses* as roof frames are called, for various spans of roof. The first, *Fig.* 40, and simplest for ordinary spans up to 25 feet say, is the King-post truss, the joints of which were described in Chapter I. This is composed of four triangles, and if the pressures and tensions, which are strictly along the pieces, are carefully studied, it will be understood that no stiffness is needed in the joints. Even loading is not necessary in this case. The roof may be put on one slope alone, and all would be safe.

55. A frame jointed in this way would, of course, not be safe against shocks, or forces acting in any way but as the load, and the explanation is only meant to show that the main matter to be attended to in framing the joints is the strain produced by the weight of the roof, and that for this, stiffness of joint is not necessary, so long as there is sufficient connection to prevent the pieces being shaken apart.

56. Queen-post trusses *Fig.* 41, are employed for larger spans. These are not really correct frames, as the centre part

is not a triangle, and this will not, in theory, stand uneven loading, without stiff joints. It is not a form perhaps of much use now-a-days.

57. *Fig.* 41, and the two following Plate VIII *Figs.* 42 and 43, will show that mere multiplication of pieces does not make a correct frame, indeed a carelessly placed piece may be almost dangerous, and that it is necessary to understand Mechanics to design a frame. *Fig.* 42 is an example given in the last Edition of this work, and is somewhat similar to an example given by Tredgold for a roof over a church, which building has usually a centre nave and side aisles as the sort of verandahs EB, E'B' are called, the walls at BB' being open ones. The roof is correct enough without the pieces BC and CD. BC was probably introduced to fix the ceiling of the centre part on to, and could do no harm, but the introduction of DC is a mistake, it either does nothing, in which case it is superfluous, or it carries some of the weight of the roof at D, in which case it is mischievous, as this must throw a compression strain down CB, which tends to thrust the two walls at B and E outwards. If the two pieces had been strapped at the ends to the other frame, so as to act as ties, it might be considered that they counteracted the slight outward thrust that the roof AF does bring on the wall at E. It should be stated that Tredgold does not give piece DC but only BC.

58. *Fig.* 43 is the Hammer Beam Truss, much used in gothic roofs. Here the pieces are arranged for architectural effect, and it is not strictly a frame. If the walls are immovable, so as to give the horizontal resistance given by the lower member of the frame in other cases, it is safe enough, if properly made, but the calculation is too involved to be given here.

59. The above two examples will suffice to show that the carpenter must not be contented with any sort of frame, however complicated. He must understand Mechanics if he wishes to make safe ones. If he may perhaps make his truss or girder so complicated, and its joints so stiff, that it is like as if it were cut out of one solid piece, then any shaped thing may be put across an opening, provided it is strong enough, but this is, of course, gross waste of material, and do not let him call it a frame.

60. Whatever form of truss may be adopted, it is put across the building at certain calculated intervals, just as in the case of beams in flat roofs, and then crossed by smaller timbering and some fashion of roof-covering.

Thus Plate IX *Fig.* 44 shows the pattern truss given in the Military Works Specifications. In this example the conditions are given as follows :—

The clear span is 24 feet. The trusses are to be $6\frac{3}{4}$ feet apart, and the common rafters $2\frac{1}{4}$ feet apart, from centre to centre. The purlins, common rafters, and battens, to be of sál wood. Roof covering, double Allahabad tiling. Slope of roof 26° 35′, or 1 in 2. Walls 18 inches thick.

61. In this arrangement the trusses are placed at certain intervals, these again are crossed by the ridge pole, at the top joint, by purlins at the next joints where the struts meet the rafters, and again purlins at the joint at the foot of the rafter. These all run horizontally. They are, in their turn, crossed by common rafters one over each truss and several between, and these are again crossed by horizontal battens placed close enough together to carry the tiles. It will be observed that the whole weight of the tiled covering and wood work above the trusses is carried on the joints of the frame, no piece of which is thus in transverse strain, but the purlins, common rafters, and battens are all *strained transversely*.

62. The length and breadth of the room were of course the first fixed facts, then the spacing of the trusses was decided much as detailed in para. 26 for flat roofs, but here, perhaps, more than for simple beams, regard is had to keeping the distance apart such that the timbers of the trusses will calculate out to a suitable size, neither too slight, or too heavy to frame conveniently. The spacing of the battens depends on the tiles, as they must just catch each lower tile at the lug, or little piece turned down from its upper edge, and the spacing of the common rafters is a convenient division of the space between the trusses so as to bring a rafter over each truss.

63. On these conditions the scantling required for each timber can be calculated out. Thus as the tiles weigh 30 lbs. per foot, and 35 lbs. is allowed for wind pressure, each square foot of roof is taken at 65 lbs., and for the battens, the weight of roof carried is $1 \times 2\frac{1}{4} \times 65 = 146$ lbs., and to carry this, the batten work out $1\frac{1}{4}'' \times 1\frac{1}{2}''$. For the common rafter in the same way the roof carried is $2\frac{1}{4} \times 7 \times 65 = 1{,}024$ lbs., and this works out $3'' \times 4\frac{1}{2}''$, and so on for the other pieces.

64. The above is worked out as a theoretical example, but the scantling for the battens is not practical, as before stated, no wood is straight grained enough to cut to very small scantlings. *Fig.* 45 will show this—in transverse strain the piece would break along the grain marked with a dark line. In this case the spacing would be altered, the common rafters would be spaced further apart, one only given between each pair of trusses instead of two, which would make the batten carry $1 \times \frac{6{\cdot}75}{2} \times 65 = 220$

lbs. instead of 146, and the scantling required would be about $1\frac{3}{4}'' \times 1\frac{1}{2}''$, which is still rather small practically, but the bearing is very short, and this might be accepted as the best arrangement that could be made.

65. It might be thought that the simplest way would be to dispense with the common rafters and purlins, and put the battens directly on the trusses. The weight then would be $1 \times 6{\cdot}75 \times 65 = 440$, and the scantling required would be $2'' \times 2''$, but this would be worse for the larger length required than the smaller size for the short length. The example is only intended to show that these dimensions are not arranged by guess, but require careful calculation to make the best of the wood.

66. The problem is sometimes worked the other way, in the case where the wood in hand is already cut up to small scantling, or into scantling which will only cut conveniently to certain sizes. Then the distances suitable for the scantlings are worked out by inverting the above described processes.

67. The foregoing is hardly more difficult to understand or arrange, and indeed is hardly more carpentry than the work on a flat roof, but when pent roofs have sloping ends run into and cross each other, as they do in all buildings of any architectural pretensions, the carpentry at the angle joints become somewhat intricate. To take a very simple case of a plain rectangular building with hipped ends instead of gables, as Plate X *Fig.* 46. The roof slopes up from the eave AB, as well as from the sides. A truss must be placed across at CD, so that its apex P will make a support for the point of the hip, and this will generally be half the breadth of the building distant from the end AB, as the slopes of the roof at end and sides will be the same. From this point P, hip rafters, as they are called, will run to the corners A and B and an ordinary rafter to centre M. If the spacing DF of the trusses is, as will usually be the case, less than BD, *jack rafters*, as GH, GK, as many as the spacing gives, are given to complete the spacing. The purlins now have an even plane of rafters to support them on side and ends slopes, and there is no difficulty about their arrangement, but the jointing of the rafters meeting at P, and even the jack rafters on the hip rafters, will require some carpentry.

68. In the first place the extra weight placed on the truss CD has to be considered, as the distance BD is generally greater than that between the trusses, and the truss itself must be designed strong enough to carry the extra weight. Then the hip rafter PA, PB, and the central one PM, must either be calculated strong enough to bear the weight on them unsupported by a strut in the centre, as the truss rafters are, or a strut must be given. These

three struts can only be supported by the King-post of truss DC, which must be made strong enough, and again their pressures will give a resultant horizontal thrust in direction MP, which must be arranged for, perhaps by a horizontal tie back to the wall on line PM.

69. But supposing all this done, then comes the carpentry to fit the several pieces together, and inspection of *Figs.* 47, 48 will show how it may be done, though details may vary. The Student must remember that he cannot just put the jacks on top of the truss, because their upper surfaces must be on same level as those of the truss rafters, to let the purlins sit fair on them, and so with other pieces, all is bound by the necessity of having a smooth roof of tiles over all. No description of these intricate figures is possible, the Student must study them and understand them.

70. Other more complicated examples might be given, and are given in the Military Works Hand-book. The "Treatise" only professes to point out the principles, not to give examples.

71. Timber Partitions.—In double-storeyed houses it is often necessary to have walls or partitions on the second floor, which have no supporting walls underneath, as the rooms in the upper storey are generally smaller and more numerous, or any way differently arranged from those on the lower floor. Hence it is evident the partition must be a real frame, suited to carry itself, and must not rest on the flooring of the upper storey at all. Plate XI *Figs.* 50, 51 show pattern of ordinary partitions between the joists of two floors. The actual frame is of necessity in the upper part of the space, to allow for the door openings, and the jointing must be arranged accordingly to suspend all below the frame from it.

72. Thus in *Fig.* 50 the breadth AB has to be spanned, and so struts AC, DB are arranged, and the frame AEFB put on them. It is made this Queen-post form to allow for the centre door, and the long posts EG, FH, are suspended from the angle E, F, and thus can carry the struts GI, HK. A straining piece or strut is necessitated between G and H, and if this cannot be given, its effect must be given by the floor by fixing the feet GH to the floor. The thrust at L and M may be taken by the wall, or by the piece LM being made a continuous tie. *Fig.* 50*a* shows the strains on the main frame. The other figures will be found to be on the same principles, but differently arranged, to suit the doorways required.

73. When the main frame is complete, it is filled up with boards *b*, *b*, *b*, whose breadth is the same as the breadth of the pieces of the frame, so that their edges make one even plane with

the frame. Laths or thin slips of split wood, about $1\frac{1}{2}$ inches broad and $\frac{1}{4}$ inch thick, are then nailed across this surface with slight intervals between them, and this rough holding surface is rendered with a coat of good plaster of lime mortar mixed with horse hair. This is done on both sides of the frame, which thus presents the appearance of a solid wall, and can be papered or painted.

74. Should it be deemed necessary, the interior of the frame can be filled in with brickwork, the frame being made proportionally strong, and the bottom sill specially stiff enough to bear the weight between the points of suspense. In this case the intermediate filling in would be occasional stout horizontal pieces, well secured to the vertical ties, so that the whole weight would not come on the bottom sill.

CHAPTER IV.

STAIR-CASES.

75. Stair-cases are needed in double-storeyed houses to give communication between the upper and lower storeys. They are often made in stone or brickwork, but only wooden ones are here treated of. They are generally inside the building, and a room or space must be carefully arranged for stairs in designing a house, round the sides of which, more or less, the stair-case is made.

76. Plate XII *Fig.* 52 is a plan, etc., of the model in the College model-room, which was made to show the various styles of construction possible, not as a pattern whole, and if the construction is clearly understood first, the designing of a staircase as a whole will be easily explained. The various parts of the framework are lettered and named in margin, on plan, and careful study of the plan will make the construction plain.

77. The first main point is the size and proportion to each other of the tread and riser on which the style, or slope and facility for ascent or otherwise, of the stair depends. The framework on which these treads and risers are supported consists of the stringers of various sorts, starting from the floor trimmer, against which they butt, and forming, with the corresponding piece under the landing, a stiff frame as ABC, *Fig.* 53, on which any weight can be safely placed, and making the firm landing. The side piece of this landing again makes a fresh firm starting point, as a landing trimmer if it may be so called, from which the next flight starts fair as from the floor trimmer of the first flight, and if a landing is given at each turn, the stair goes on safely *framed* to any height.

78. But to economise space the turn is often made with steps as shown at the second turn, which are called winders. These are supported on scantlings fixed as cantilevers into the wall, and also by their framing into the newel post, but this makes a figure as AB, B′C, *Fig.* 54 which of course for its own strength depends entirely on the stiffness of the joints B, B′, and therefore is not a frame at all. Hence special care is

necessary with these winders to see that the carpentry is good and the horizontal pieces strongly mortised into the newel, unless all dependence is placed on the piece as a cantilever from the end where it is built into the wall.

79. When the second flight is parallel to, and close to, the first, *see Fig.* 1, so that the balustrades of the two flights are over each other, the stair is called a *dog-legged* stair. When there is a space between the flight, as *Fig.* 2, it is called a *geometrical* stair. If the landing is square, as the first in *Fig.* 52, it is called a quarter space, if it runs right across, as in *Fig.* 1, it is a half space.

Fig. 1.

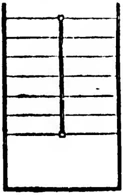
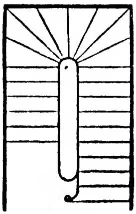


Fig. 2.



80. The plan of a stair-case is designed with reference to the above noted possible ways of making it, but it should be designed at the same time as the house plan is made, and the two made to accommodate each other. There must always be a space or well appropriated in each storey for the stair-case, round the edges of which more or less the stair-case is built, and arrangement must be made first, that the foot of the stair is in a convenient spot; secondly, that no door out of the well is interfered with; and thirdly, that the opening over the stair in the upper floor must of course be long enough to clear the heads of persons ascending; and lastly, that the last step must give on to a fair open space, not against a wall, or just into a corner in the upper storey.

81. The circumstances differ in each case, but the first fact in all is the height between the two floors, which is quite independent of the stair case. If this was 20 feet, and a nice easy stair was needed, then 6 inches might be taken for the riser, but suppose it was 19 feet, then a slightly less riser would be taken; or again, as the design went on, if it was found that 40 steps did not suit, a slightly larger rise might be assumed, but any way, a certain number of steps of the same rise would be arranged to make the *exact* height. But suppose 40 steps were decided on, we should then decide the tread suitable to the rise, say 12 inches, and 40 times 12 inches, or 40 feet, gives the full length of the stair-case or steps, and this would be sketched down in an assumed well, with suitable

landings, which would of course add to the 40 feet length, etc., and the one altered to fit the other and allow for everything.

82. In buildings of architectural pretensions the stair is designed as an important part, and the well made to fit it, and indeed this should always be the procedure; as nothing is so awkward as to have a fixed size of well made with no regard to stair, and to try and fit a stair into it. After having laid down the plan of the stair, the carpentry of its frame would be attended to, but this would have been in the designer's mind all the time, so that there should be no difficulties at this stage.

83. Plate XIII *Fig.* 55 gives a simple example of a dog-legged stair. The stair starts at A, clear of the door to the left. In the right hand wall doors may be given anywhere, as the stair is above them, and in the left wall another door can be given under the first flight at the far end of the well. In the upper storey the only place where a door cannot be given is in the space BC, where the floor must be cut away to clear the head of any one coming up the stair.

84. *Fig.* 56 is another plan for a house with a larger entrance hall, but there may evidently be hundreds of plan to suit varying requirements.

85. A spiral stair-case is one of nothing but winders, each supported on its own bearer, which in this case will generally be, and in all cases may be, the riser. If the stair is in a circular tower, and all the bearers are built into the masonry, and also framed into a central post, which rises from the ground up the centre of the stair, each step is, of course, a plain beam supported at both ends. If again, the breadth of the stair is less than the radius of the tower, and the stair winds up the wall, each step is dependent on its cantilever bearer built into the wall; or again, if it is the other way, a spiral winding round a central pillar or pole with no outer support, each step depends on the stiffness of the fixture of its cantilever at the inner end to the central post.

CHAPTER V.

DOORS AND WINDOWS.

86. Joiners' work.—DOORS. The door and door frames are two distinct parts of the *house-fitting*. The door frame consists essentially of four pieces—two called stanchions or posts, a top sill or lintel, and a ground sill. For external doors, the parts are generally of solid timber cut with a rebate on the inner faces for the door to shut against; the top sill or lintel is almost always of solid timber, as even if it has no superincumbent weight to carry (which it should not have), the stability of the door depends much on the bonding of the top sill into the wall. The ground sill is generally of hard wood or stone, in order to withstand the wear of the traffic. The framing together of these four pieces is done in the manner of ordinary carpenters' framing, and the timber is generally wrought or planed. It is fixed in the reveal constructed in the wall to keep the wind and rain from passing between the frame and the wall; hence an external door always opens inwards, an arrangement suitable both for convenience and defence. The frame of an internal door may be made in the same manner as that of an external door, and set in a reveal in the wall; but it is usual in ordinary houses to line the whole of the door opening in the wall with wood for the sake of appearance, and the vertical and top pieces of this lining are used as the posts and top sill of the door frame; hence an internal door frame is a kind of box, the pieces of which are dove-tailed together, and are thick enough to allow of a rebate being cut in them for the door to shut against. As the efficiency of a door frame depends more on its stiffness than its strength, the scantlings should never be very small; probably 3″ × 3″ is the smallest section that should be given to any solid door frame, and a barrack solid door frame should be 4″ × 4″. An internal door should be flush with the wall of the room it leads into, and should open into the room.

87. The door itself is composed of a frame of four or more pieces, consisting of two verticals, called *styles*, one horizontal at the top, and another at the bottom, called the *top rail*, and *bottom rail*, and two more intermediate horizontal pieces, called the *lock rail* and *frieze rail*, and sometimes an intermediate style

(called moutant, mounting, mullion) to reduce the breadth of the panelling, according to the mode of filling in this frame-work the door receives its technical name. The rails are framed in between the styles with common mortises and tenons, driven up tight with little wooden wedges. The intermediate styles are framed in between the rails. The filling in is sometimes of boards or battens nailed against the frame-work, or let in flush with the frame-work on one side ; this method is generally used with common doors as for barrack rooms, and is called a *framed and battened door.* Sometimes the filling in is of thin panels of wood mortised into the frame with a continuous groove all round ; this is used with doors of more important rooms, and is called a *framed and panelled door.* It is the strongest description for ordinary purposes. In large battened doors a diagonal brace is sometimes introduced extending from the upper outer corner to the lower inner corner.

Fig. 1.

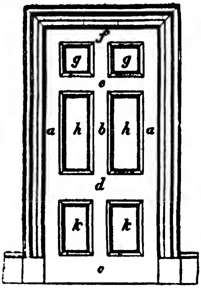
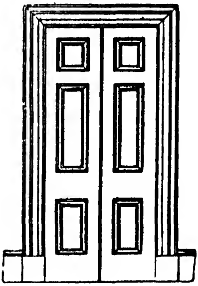


Fig. 2.



In ordinary framed doors, the top and frieze rails are generally of the same width as the styles, the bottom and lock rails generally twice as wide. In *Fig.* 1, *a*, *a* are styles, *b* the moutant, *c* bottom rail, *d* lock rail, *e* frieze rail *f* top rail, *g* frieze panel, *h* middle panel, *k* bottom panel. When a doorway is closed by two doors of equal width hinged to its opposite jambs, the middle or meeting styles are frequently rebated and beaded ; such a door is termed a *double-margined* door or *two leaved* door. Doors also which, whilst they are in one width, are framed with a wide style in the middle, beaded in the centre in imitation of the two styles of a two-leaved door, are also called double-margined doors. *Fig.* 2 shows the appear-

ance of the two-leaved and double-margined doors. A sash door is one which is glazed above the lock rail.

88. The above applies to doors in Europe, but in India, at all events in the plains, doors are almost always made in two flaps meeting in the middle. This is necessitated by the larger size used in a hot climate. But as a rule, in ordinary house building far too little attention is paid to using seasoned wood, the scantling used for the frame-work is too light and the carpentry is inferior, therefore under the great trial of the heat the results are as every one sees and suffers from. If good wood and enough of it is put together by wood carpenters, there is no reason doors should not keep out the air and dust. The tenons, on which much, if not all, of the firmness of the frame depends, must be thick enough to stand the racking strain when the doors are banged and shut, and this cannot be unless the styles and rails are sufficiently thick.

89. The great majority of doors in India are glazed, and it is too common to see the small-sized glass, which only was obtainable some years ago, adhered to, while now large panes are easily obtained, and are quite cheap and make much handsomer doors. In designing doors also, care should be taken to start with the market sizes of glass ; it is very awkward, if to mend every broken pane, one has to be cut to the size of the door openings.

90. Plate IV *Fig.* 57 gives all the details of a good door half panel half glazed, from which a drawing for any-sized door can be made out.

91. There are three kinds of windows. The Sliding sash, the Casement, and the Swinging window.

1st. The Sliding Sash.—A visit to the model-room will make this quite plain, while description must of necessity be most tedious. The window or sash is made wholly glazed in two pieces, each full breadth, but half depth of the opening or frame. Instead of being hinged to the frame as in the case of a door, these slide vartically up or down in grooves in the styles. The styles are made, not of a solid piece, but of thin boards framed together, their projections making the grove, *see Fig.* 58 : a study of this figure will make the construction quite plain. The two sashes are side by side and the lower can be slid up to cover the upper, or *vice versâ*, or both slid to the centre half of the openings, but only half the opening can be opened. It is a convenient form for ventilation, as the lower sash can be raised and the upper lowered a little, leaving an opening to let ingress of fresh air, while the hotter air escapes at the top opening. There are little pulleys fixed at the top

of the framed styles inside, over which run cords weighted at one end and attached to sash at the other, which balance the sash in any position. The sash fits into a rebate on the top and bottom sill respectively, and their bottom rails meet in the middle with a slope on either, so as to form a close joint. *see Fig.* 58.

92. Sometimes the sash is made in one piece, but then the frame must be double the size of the sash, and half of it let into a hollow slit in the wall above or below, into which the sash can slide.

93. *2nd. Casement Windows.*—These are in every way similar to doors, *i.e.*, made in two leaves and hung on hinges. If they are in outer walls, they, just as doors, require very careful setting in their frames and over-topping fairly where they meet to keep out rain or wind.

94. *3rd. Swinging Windows.*—Another method of arranging the opening of a window, common in factories, barracks and any lofty rooms, is by swinging it on two horizontal pivots in the side styles, a little above the centre of their height so that it is opened and shut by means of two lines, one from the top rail, and one from the bottom, the upper part opening inwards and the lower part opening outwards. This is therefore an advantageous plan for windows out of ordinary reach of hand. The horizontal sash bars in this window should extend continuously across, and there should be a centre rail to hold the two pivots. It is easier to make this window water-tight than the casement window, because a rebate forming an effective stop can be cut in the inner side of the top part, and the outer side of the bottom part. It is not applicable to large windows on account of the strain from the mode of hanging.

The weight and strength of a window depends much on the thickness of the wood work, as in the case of a door ; 1¾ inches is a suitable thickness for an ordinary barrack window. The sash bars are generally the same thickness as the frame.

CHAPTER VI.

CENTRES AND STAGING.

95. Centres are "frames" for supporting the stones or bricks of an arch during its construction. They are placed across the span just in the same way that roof trusses are, and are crossed by timber scantlings called lagging, just like the purlins of a roof, only that they must be placed closed together to allow of the arch stones being laid.

96. The main points in which the case differs from a roof, is that the load to be put on is much heavier, and that as it is gradually put on, the frame must not change shape in the least; and that as the arrangement is only temporary, it must be made so that it can be easily taken to pieces, and so that the wood used shall not be cut up or spoiled in any way with spikes or holes more than absolutely necessary. The frames and lagging must be calculated to stand the weight it will have to bear withont bending in the least, and as the wood should not be spoiled, there is no advantage in stinting the dimensions of the scantlings, except that they should not be too heavy to get into position.

97. *Pressures on Centres.*—It is usually stated that the arch stones do not press on the centre if the face of the joint is less steep than 30°, or to put it the other way, that only 60° of the arch on each side of the crown presses on the arch. The weight of any voussoir or course may be considered as represented by OW, Plate XV *Fig.* 59, and this may be resolved into OP and OQ, of which OP is entirely counteracted by the surface of the stone below, and OQ entirely tends to make the stone slide on the face of the one below. If this force OQ is greater than the friction between the two surfaces, the difference will fall on the centre as a normal pressure, *i.e.*, perpendicular to the curve of the arch at that point.

98. The friction is a certain proportion of the pressure OP, dependent of the roughness of the surfaces, the mortar, etc. The pressure, therefore, between any two courses evidently increases as more courses are laid above it, as their pressure is passed on downwards; and, therefore, there is no fixed slope

at which the force OQ is greater than the friction even for one material, and of course it varies with the material, and exact calculations are therefore impossible.

99. From the first course of voussoirs that presses on the centre, each successive one presses more, till at the crown the course acts with its full weight, and the frame must be made to stand this gradually increasing pressure. For the pressure of any particular course it will be sufficiently accurate if we consider that of the key-stone its own weight W as AB. *Fig.* 60, and that at 60° from it as shown by the point C, BC being made the length of the arc from crown to 60°. Then the pressure of a course at any distance from the crown as BD will then be DE, or if BD subtends an angle a at the centre, the pressure of the course will be $\frac{(60-a)W}{60}$, where W represents the weight of a course as before.

100. If BC is marked off with the thickness of the voussoirs, the rectangle BZ represents the weight or pressure of the central course, and each successive breadth with the portion of the triangle above it, represents the pressure of that particular joint. Thus triangle ABC represents the whole pressure, and EDC the pressure of the arch when completed to D.

If the arch is less than 60° on either side of the crown the figure ABC will be made just the same, C being 60° from A, but all beyond the springing of the arch will not come into the case. Say the arch really sprang from 45° either side of the crown, *i.e.*, only extends to X, then CXY does not exist, the pressure at springing is XY, up to D it is trapezoid XYED and on half arch XYAB.

101. *Construction of Centres.*—In very many cases temporary intermediate piers or supports of some kind can be built up from the ground below, and this makes the construction very simple. In this case a frame to span the whole interval is not needed, the construction becomes a series of struts from the several supports to a number of points on the curve, braced together for general stiffness, of which *Figs.* 61 to 64 are examples.

102. But when intermediate supports are not available, the centre must be a perfect frame, and moreover a very stiff one. The place of the tie-beam can be supplied by the resistance of the abutment and piers, care being taken that the outward pressure on the latter, which are sometimes slight, is not too great.

103. For a number of small arches the arrangement shown in Plate XVII *Fig.* 65 is convenient enough. It can be easily set up and taken down and used again, but the arch must be carried up very evenly from both sides, as a greater weight on one side than the other would cause distortion, and indeed tiebars screwed on across the angles in any case would be a great and necessary addition.

104. *Fig.* 66 is a step in advance of the last fer a larger span. The centre starts from a support, both in this case and the next, which is only very sketchily shown in the figure, and would need to be steadier than there shown. But in this figure the two triangular trusses EDC, E'D'C meet at C, and form a stiff frame, thus giving stiff points EDC D'E'. The pieces DF, D'F' are no use without IFF'I', but resting on the points FF' of this frame they strengthen the points DD'. The curved ribs between the points ED, DC, CD', D'E' must be strong enough to bear the transverse strain of the load for their length.

105. *Fig.* 67 is a frame for a larger span again. This is three frames BEFH, HFF'H', H'F'E'B', a similar case to the first one given in para. 103, only made in one frame ; but again might act as a compression frame EFF'E' and struts from it to the curve, as when the frame is complicated by extra or unnecessary pieces it is very difficult to say what result the weight will have on it as to putting the members in tension or compression, and therefore a frame cannot be too simple, as it is very difficult to make wooden joints to resist both compression and tension, as either may be called for.

106. Plate XVIII *Fig.* 68 shows the centres used for the Warda Bridge, of 7 arches of 50 feet span. Three sets of centres were used of five frames in each set ; each frame weighed about 1½ tons.

107. In putting up centerings regard must be had to the facility for taking them down again. They have to be eased, that is, lowered an inch or two as soon almost as the arch is keyed, and then shortly afterwards taken away without shaking the still green masonry of the arch, and often put up again for the same bridge. Thus, for the Warda Bridge, the three arches from one abutment were built on the three centres. Then centres of 1 and 2 were taken down, and put up in spans 4 and 5, and then again 3 and 4 taken down and put up in 6 and 7. The last of the completed arch in the first and second cases, *i.e.*, 3 and 5, could not of course have its centre removed and the pressure of the arch transferred to the pier till the arch on the other side of the pier was made.

108. This lowering of the centres is done by wedges, sand bags, or cylinders or boxes, or jack screws, by all of which it can be done very gradually, and to any extent required, *i.e.*, the lowering can be stopped at any moment. There are of course a great number of wedges, etc., under a large centre, and the only way to secure gradual lowering of the whole is to order the man in charge of each to lower, say 1 inch, and then wait for the signal to lower another inch, and so on, as once the lowering starts, the hammering the wedges and creaking of the loosening frames makes such noise and confusion that no orders can be heard.

109. It is also most essential that the top of the supports should be steady and firm. Masonry pillar supports must always have wooden tops to make the top solid ; and they should, if possible, be all connected together by beams, on which connected platform, as it were, the lowering arrangements are fixed ; and similarly, the bottom of the frames should be large timbers, or the frames should all be set on one large timber, so that no lowering of one point accidentally, more than intended, should be able to affect one frame only and produce distortion.

110. The various means used are all worked in the same way between these two connected planes, *i.e.*, the top of the supports and the bottom of the centre frames.

111. *Wedges.*—These are always used in pairs, and must be very carefully made of stout scantling, so that they can be hammered without breaking the thinner ends. They should be sloped on one side only, so that the top and bottom of a pair is level. The fineness of the wedge of course depends on the slope, and not on the thickness of the pieces. Their thickness should be fitted to the purpose *i.e.*, the depth between the two planes above-mentioned, or made up to it with square packing pieces, so that when fixed or driven into position, they may be as required *i.e.*, with their ends out and clear for striking, *see Fig.* 69, under a centre, where their work is to lower, or the other way, as *Fig.* 70, if needed to raise anything. When fixed tight, lines should be drawn on one and a mark made on the other, by which the alteration of level caused by driving them can be at once known. In lowering a centre the hammer-men at each wedge would drive one or two lines as ordered, and then wait for signal to commence again and drive another one or two. Some wedges are sure to stick, and some to drive easily, and no regularity will be attained without this precaution. It used to be the fashion to make these wedges under a centre all connected, so that they could be driven from outside, and no one need go under the arch while the centre was being eased ;

but this cannot well be arranged with sand boxes, and no centres or arches should be built so badly that such precautions should be necessary. Students may see the arrangement in the models in the Model-room.

112. *Sand bags* are merely bags of strong gunny cloth with mouths at both ends, filled with fine dry sand, and put in between supports and centres. When the arch has to be lowered, the mouth of the bag is untied, and the sand runs out and the centre descends ; by gathering up the mouth of the bag in the hand again, the flow is arrested and the lowering stops but this is the roughest way in which sand is used.

113. *Sand cylinders* are made of iron. No tops or bottoms, just pieces of a 12-inch diameter pipe, about 12 inches long. These are placed on the flat wood tops of the supports and nearly filled with sand. A solid wooden cylinder, 10 or 12 inches high, and of slightly less diameter than the inside of the pipe, is then placed on the sand, and the centre is built on the wooden cylinder or piston. Near the bottom of the iron cylinder are several holes of 1 inch diameter, stopped with corks or wooden plugs. When it is required to lower the centres, a man is placed at each cylinder, and at a given signal withdraws one or more plugs and the sand runs out, and the piston and with it the centre descends. The piston is marked with horizontal lines an inch apart, and when the man sees it has gone down an inch, he either puts in his plug again, or ceases to remove the sand which has accumulated on the board in front of the hole, which is of itself usually sufficient to check the motion. Each man has a little iron rod, with which he can stir up the sand inside through the plug holes if it should be found caked and not inclined to run.

114. *Sand boxes* are just the same, only that instead of cylinders stout wooden square boxes, bound with hoop-iron, are used with a square piston.

115. *Sand tins.*—Heavy arches have been put on kerosine tins filled with fine sand and soldered up, a hole being punched in one side to allow the sand to flow out when required. The advantage claimed for this is that they can be more cheaply made than cylinders or boxes, and that the sand is kept dry ; whereas in the others, being open to the air, it is apt to get wet and will not run if the arch is long in building.

116. If the centre is to stand any time, it is best to put in the sand arrangement, whether cylinders or boxes, only just before the centre is to be lowered. For this the space between the supports and centre, necessary for the lowering arrangement, sand bag or whatever it is, is preserved by blocks of soft wood, one at each place where a sand box will be required, and the arch built. When the sand box has to be placed, two pairs of wedges

are fitted in, one on each side of the block, and driven till the centre frame is slightly raised, and the block can then be knocked out. Soft wood is specified, so that if the wedges fail to raise the frame enough to loosen the block, it can be easily cut out. The sand box is then placed in position, and a pair of thin wedges driven between the top of its piston and the centre frame, till it takes the whole weight, and then the side pairs of wedges are knocked back and taken away to place the next sand box. Of course wedges can be placed instead of the soft wood block if desired.

117. In the above instances, a man to each sand box has been specified for lowering, but this is not really necessary, except to save time. The lowering at each point is so small at one time, that the whole can be done by one man, if desired, lowering each piston half an inch at a time in succession.

118. It is an additional safeguard, and indeed should always be done when bags are used, to have stop blocks at each point. Thus, if the height of the sand bag, etc., is say 8 inches, to have three slabs of wood 2 inches thick placed on the tops of the support close by, so that the centre cannot go further than to them, *i.e.*, 2 inches, and then another slab is removed to allow 2 inches further descent, but with proper boxes or cylinders this should not be necessary.

119. *Staging.*—When large iron bridges with horizontal girders have to be erected it is generally necessary to construct a stage or platform with a flat surface just under the level of the bottom of the girders on which the girder is built, as the process of rivetting and bolting its component pieces together is called. This platform often has to be at a great height above the ground, 70 or 80 feet being quite a common case. The main feature of these stages is usually a series of trestles, made of large square timbers, but as the load to be borne is simply a vertical weight, their construction is fairly simple, the pieces being halved into each other and bolted as *Fig.* 4, *Plate* I., and a sufficient number of lighter, but still stout pieces, are bolted on diagonally to ensure the lateral stiffness of the trestle. Plate XIX *Fig.* 71 gives a fair example. It is the staging used at the Mahanuddy Bridge on the Bilaspur-Etawah State Railway by Mr. Groves, Executive Engineer, in 1886, and the following is his description of its erection for the model he sent to the College Model Room :—

"This model represents the temporary timber staging used in the erection of the lattice girders of the Mahanuddy Bridge on the Bilaspur-Etawah State Railway, there being four spans of 100 feet each, and one of 80 feet, with railway carried on rail and cross bearers between main girders, rail level being 70 feet above bed of stream. The main girders of 100 feet span weighed about 23 tons each, and the cross girders 11¼ cwts. each.

"Each of the five trestles supporting the staging was securely fitted, while lying flatwise in the bed of the river, and the heel timber being placed near one of the piers, the trestle, weighing about 12 tons, was hauled up vertically and guyed. All five trestles being successively made and similarly placed in that position, close to each other and to one pier, they were then easily slid into position shown in the model, being kept vertical by careful manipulation of guys.

"In striking the staging the trestles were slid back to original position near the pier, and lowered one by one flatwise on to bed of the river, and hauled in that position to the second span beyond, where they all were re-erected as in the first span. This arrangement proved more rapid of execution than if the trestles had been built in position and dismantled in order to be rebuilt again.

"The platform* was composed of broad gauge sleepers resting on groups of flat-bottomed broad gauge rails, which were again supported by cross girders of the permanent bridge, used temporarily, resting on the trestles. The open nature of the platform allowed of constant look out on all parts of the staging against fire. All lifting and hauling of trestles and ironwork of the permanent bridge was effected by the aid of steam hoists.

"The teak timber was purposely designed 10″ × 10½″ and 10″ × 5″, so as to cut up into broad gauge sleepers at close of the work. The model was made by Private Hand, Roorkee Apprentice, from designs of the undersigned, at a scale of 4 feet to the inch."

120. Another specimen of a more extensive staging is given in the Model Room, being the model of the staging for the erection of the abutments, or rather pillar and guy, of the cantilever of the Lansdowne Bridge, kindly sent by Mr. Robertson, the Engineer of the bridge. This is just sketched in *Fig.* 72. Here the design and joint of the frame-work may seem simple enough, but the enormous size of the structure necessitates most careful good work, as an ever so small error in squareness or tight fitting in the lower parts would be magnified up at the higher stages and produce dangerous results.

The following is Mr. Robertson's account of the erection. The student should consider how solid the framing must have been to allow of the footing of the derrick, a 70 feet beam, at various heights on it as the structure grew :—

"The Sukkur Bridge is a Cantilever Bridge of 820 feet span of the outline shown in sketch. The ironwork in the model is the Pillar and Guy. The former is 169 feet high to centre of top, 100 feet apart at base and 20 feet at top.

"This staging is for the purpose of erecting the main pillars and guys of the 820 feet cantilever span of the Sukkur Bridge, one each side of the river, the design being the same for both. It is rendered necessary by the design of the pillar, which has no stability in a longitudinal direction till connected to the guy, and is built with a backward rake to give the required camber to the nose of the Cantilever.

"Total height of staging 177 feet. Timber mostly pitch pine 12″ × 12″.

"The inclined back of the staging forms a tram 8 feet gauge over each guy, up which a small traveller is drawn by a wire rope. From this hang the pieces of the guy by a differential block, and by this they are drawn up and placed in position, and the traveller also transports the hydraulic rivetter.

* Not shown in figure.

"In erecting a staging of this height, great care is necessary to keep it plumb, and on account of the warping of the timber, the only way to ensure accurate work is to have all the boring done below to template, and to allow no tampering with the holes aloft.

"All the splices are bored to one template, so that any fish will fit in any place, and as the posts do not always hold the exact scantling from end to end, the end centres are carefully marked, and a one-inch diameter iron dowel let 4 inches into each post. This ensures every length being truly central.

"The augur holes are bored with a guide, so that they are truly square, and no difficulty is experienced in getting the bolts in aloft.

"The walings are also bored to template, so that when the posts at the low end have been placed perfectly plumb and strutted from the ground, the waling brings the other posts vertical. The struts are then measured for with an expanding template.

"The erection was done with a derrick pole and a gang of men hauling on the fall of the tackle. The derrick was placed on a platform resting on the walings. All the posts of one setting were first hoisted by the derrick and bolted into place, then a waling in both directions. From these walings blocks were hung as required to lift the remaining pieces. The staging stands on rock, a long sill being placed reaching across two posts where fairly level, but where the rock is rough, and this would have involved much blasting, a short sill only is given. There are 54,127 cubic feet of timber in the two stagings, and the total cost is—

		Rs.
Pitch pine timber	... ...	48,938
Deodar	... ...	56,483
Labour	... ...	39,199
Stores	... ...	15,388
Foundations	... ...	2,573
	Total ...	1,65,581

"To which must be added Rs. 8,000, the probable cost of pulling down and disposing of the timber and ironwork.

"The timber had all to be kept on one side of the river, and after being fitted was towed across by row boats.

"The item Stores includes all the staging bolts and other ironwork, such as dogs, glands, etc., and an item of Rs. 5,000 for depreciation of cordage used in the work.

"Foundations, represents the cost of blasting, and levelling rock.

"The item pitch pine timber, demands particular notice. This, which was selected, and sawn, is in lengths averaging 40 feet by 12 inches square, and with scarcely a knot, certainly with no bad ones. The cost of this, delivered at Sukkur, was Re. 1-10 per cubic foot, while at the same time the cost of deodar only 6 feet long supplied by the Railway Store Department was Re. 1-14. The nominal price of deodar is one anna per foot length in the log, but as a matter of fact it is almost impossible to procure timber over 25 feet long.

"The price therefore at which first class pitch pine can be procured, cannot be too widely known, for even were the timbers the same price, the pine is far better, being much stronger and free from knots.

"Finally, it should be noticed that each staging is provided with two large lightning conductors, which are further assisted by the rails of the traveller run."

JOINTS.

Fig. 1.

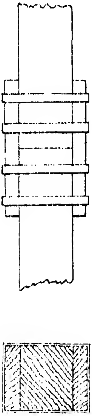


Fig. 2.

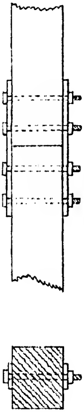


Fig. 3.

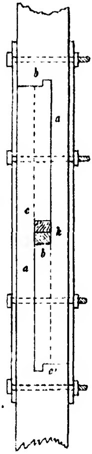


Fig. 4.

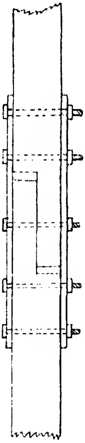
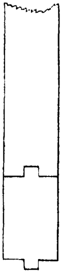


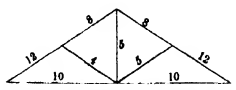
Fig. 5.



No Scale.

JOINTS.

Fig. 6.



Figures show strains in 1,000 lbs. roughly, in an ordinary 20 feet roof.

Fig. 7.

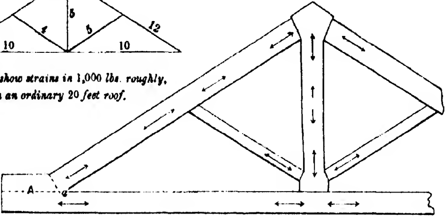


Fig. 8.

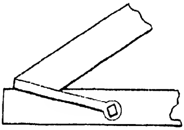


Fig. 9.

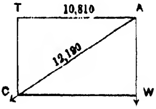


Fig. 10.

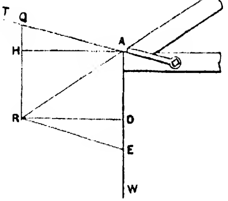
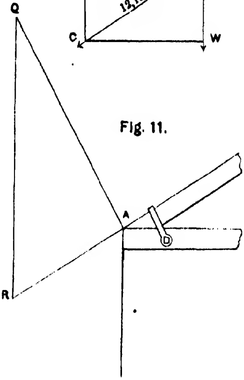


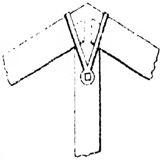
Fig. 11.



No Scale.

JOINTS.

Fig. 12.



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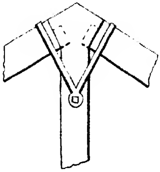


Fig. 14.

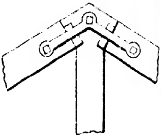


Fig. 15.

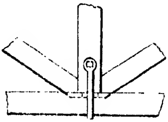


Fig. 16.

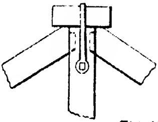


Fig. 18.

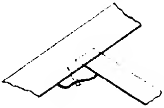


Fig. 17.

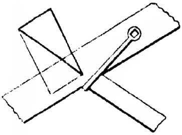
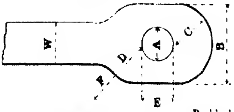


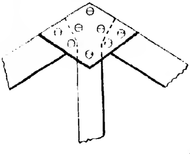
Fig. 20.

Fig. 21.



			Berkley's.
Width of link, ...	W	=	1·00
Diameter of pin, ...	A	=	·75
Width of eye, ...	B	=	2·00
Radius of back, ...	C	=	1·00
„ of front, ...	D	=	1·00
Distance apart of centres for radii C and D	E	=	·75
Radius of shoulder,	F	=	1·5

Fig. 19.



No Scale.

FLOORS.

Fig. 22, *No.* 1.

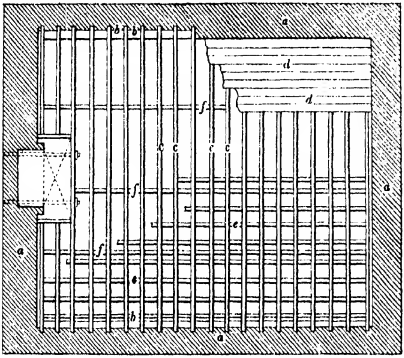


Fig. 22, *No.* 2.

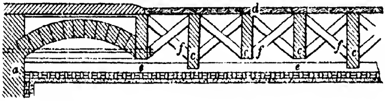


Fig. 23, *No.* 1.

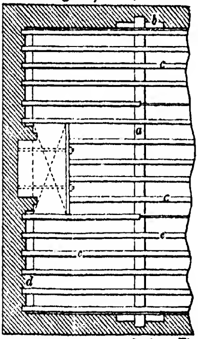
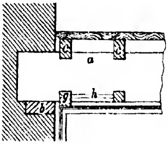
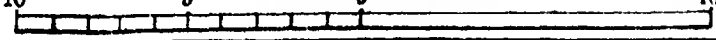


Fig. 23, *No.* 2.



Scale to Figs. 22 *and* 23.



FLOORS.

Fig. 24, *No.* 1.

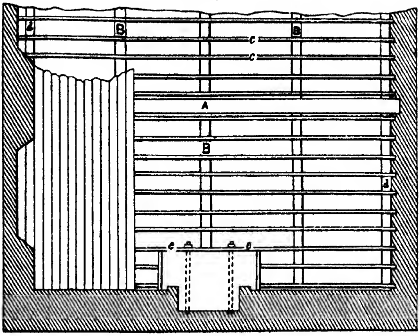


Fig. 24, *No.* 2.

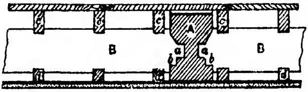


Fig. 25.

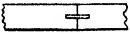
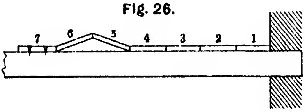
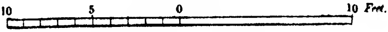


Fig. 26.



Scale to Fig. 24.



Scale to Details, Fig 24, *No.* 2.

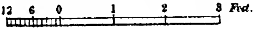


Photo.-Mechl. and Litho. Dept., Thomason College, Roorkee.

No. 832-12.

Fig. 27.

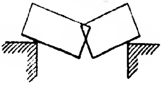


Fig. 28.

Fig. 29.

Fig. 30.

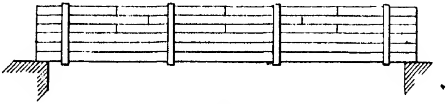


Fig. 31.

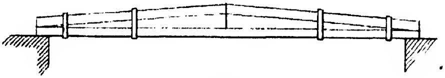


Fig. 32.

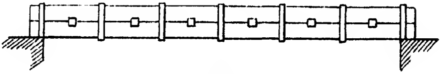


Fig. 33.

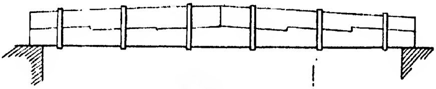


Fig. 34.

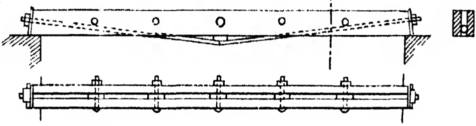
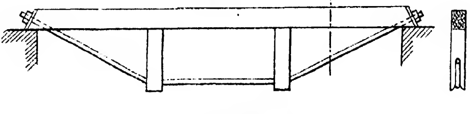


Fig. 35.



No Scale.

Photo.-Mechl. and Litho. Dept., Thomason College, Roorkee.

Fig. 36.

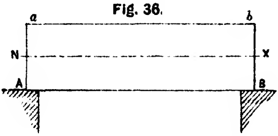


Fig. 37.

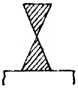


Fig. 38.

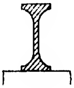
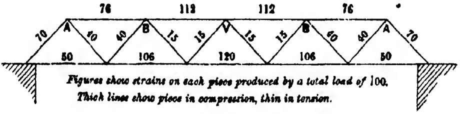


Fig. 39.



Figures show strains on each piece produced by a total load of 100.
Thick lines show piece in compression, thin in tension.

Fig. 40.

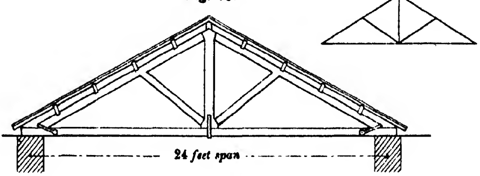
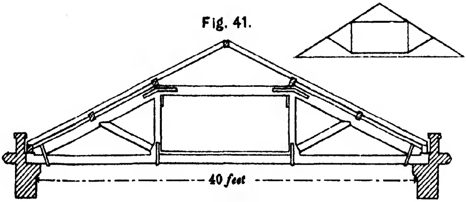


Fig. 41.



No. Scale

Photo.-Mechl. and Litho. Dept., Thomason College. Roorkee

NO. 832—14.

Fig. 42.

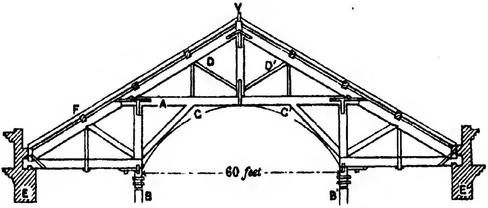


Fig. 43.

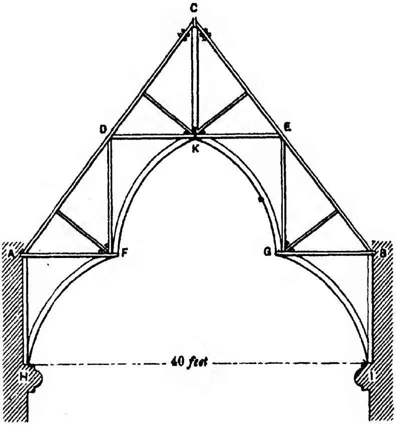


Photo.-Mechl. and Litho. Dept. Thomason College, Roorkee. No. 832-18.

KING-POST TRUSS.

Fig. 44.

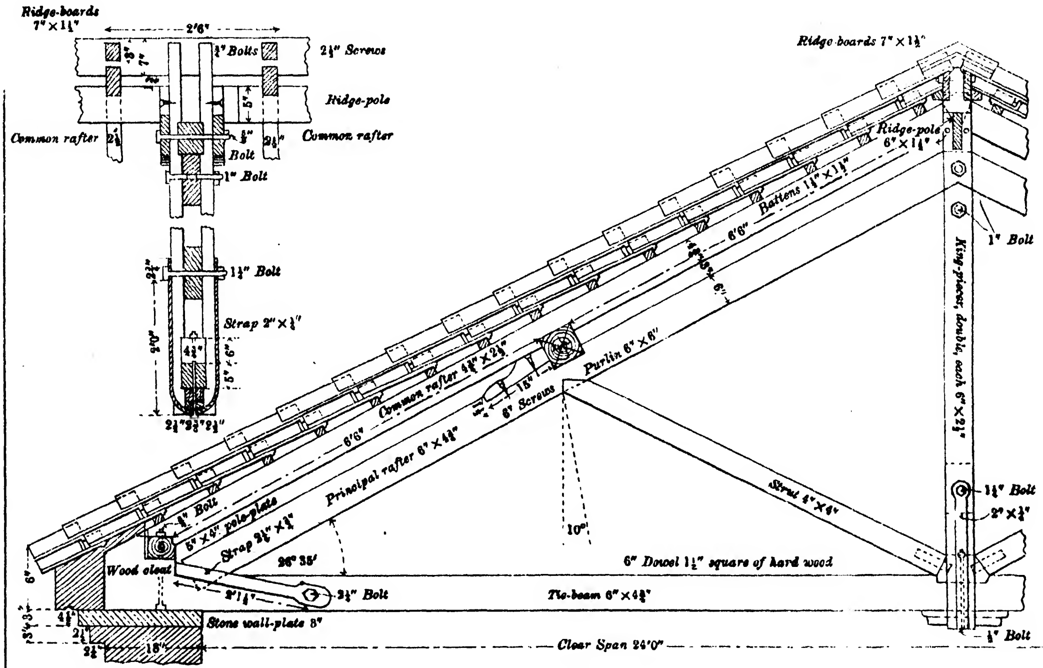


Fig. 45.

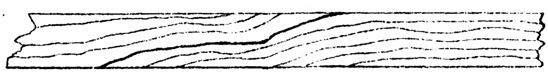
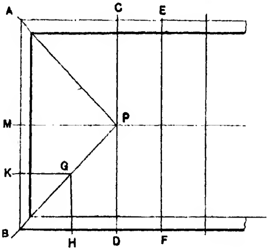


Photo.-Mechl. and Litho. Dept., Thomason College, Roorkee.

Fig. 46.



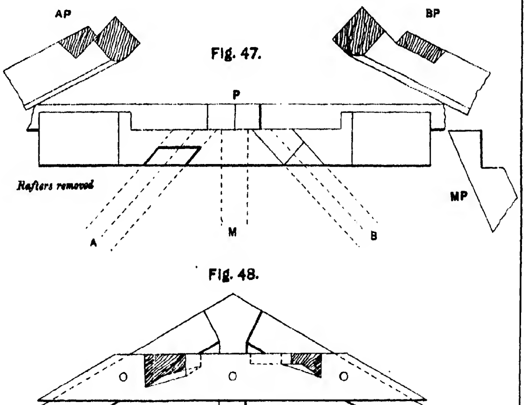
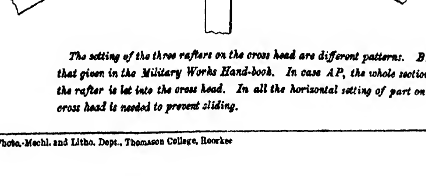


Fig. 48.



The setting of the three rafters on the cross head are different patterns. BP is that given in the Military Works Hand-book. In case AP, the whole section of the rafter is let into the cross head. In all the horizontal setting of part on the cross head is needed to prevent sliding.

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No 832-17

PARTITIONS.

Fig. 50.

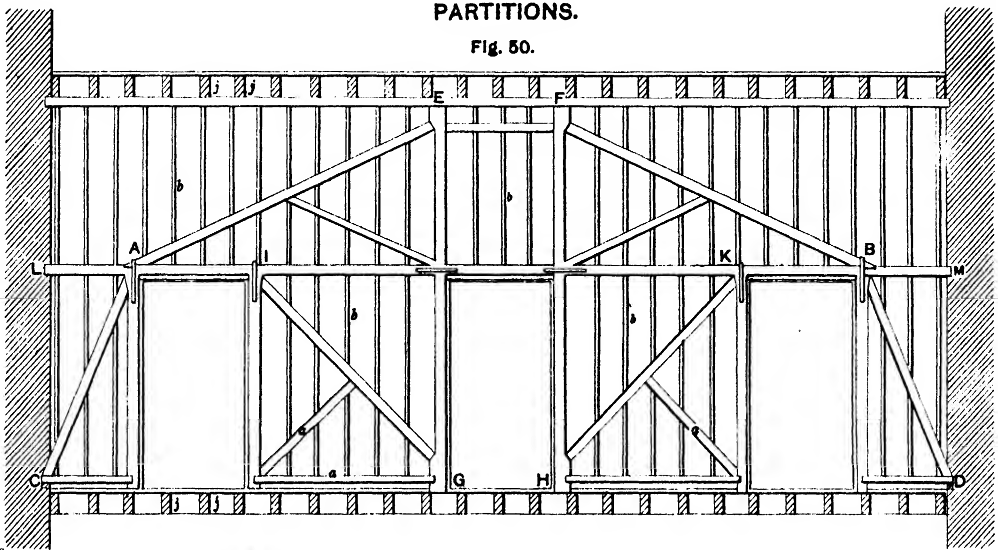


Fig 51.

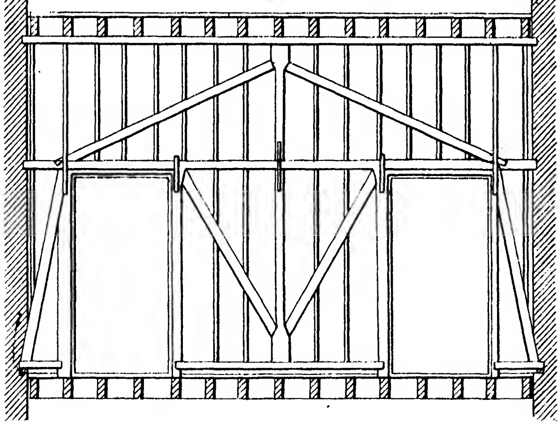


Fig. 50*a*.

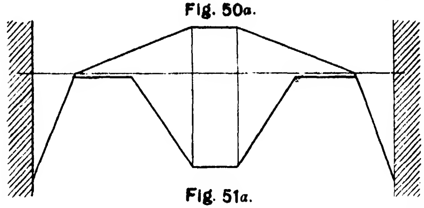
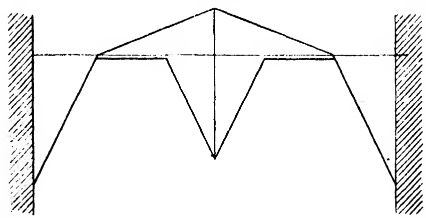


Fig. 51*a*.



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No 332 · 18

Fig. 52.

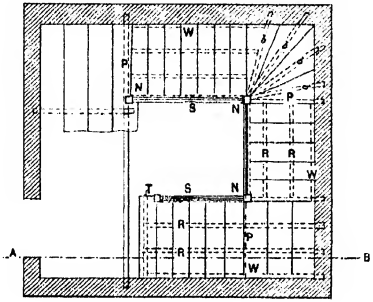


Fig. 53.

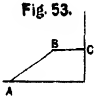
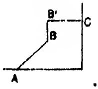
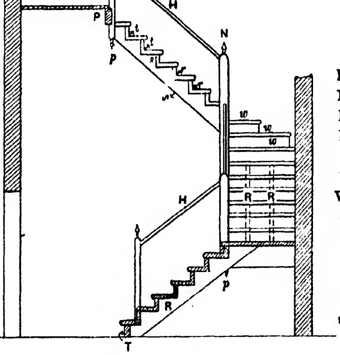


Fig. 54.





SECTION ON A B.

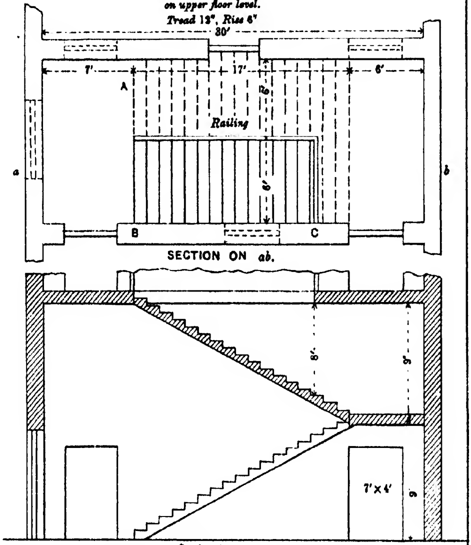
REFERENCES.

H. Handrails.
N. Newels.
P. Pitching piece.
R. Rough string.
S. String board.
T. Trimmer.
W. Wall string.
b. Long bearers.
p. Pendant.
r. Riser (deal).
s. Soffit (lath and plaster)
t. Tread (oak).
w. Winders (oak).

Photo.-Mechl. and Litho, Dept., Thomason College, Roorkee.

Fig. 55.

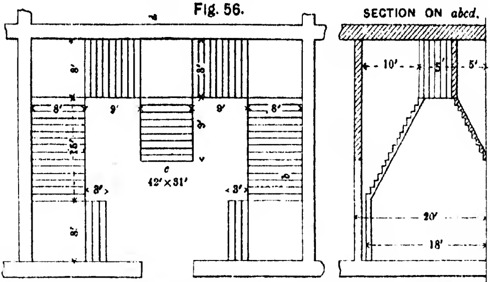
PLAN.
on upper floor level.
Tread 12", Rise 6"



PLAN. *Scale* $\frac{1}{100}$

Fig. 56.

SECTION ON *abcd.*



Opening in upper floor only needed over these two side flights 15'×8', the landings and last three steps.

Scale $\frac{1}{200}$

Tread 12", Rise 6".

Fig. 57.

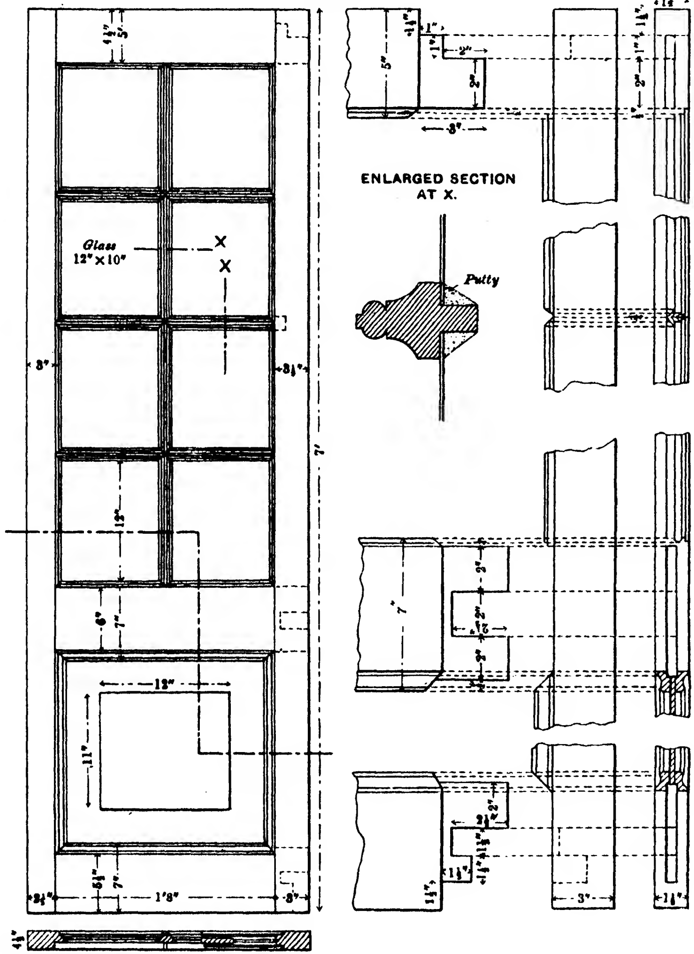
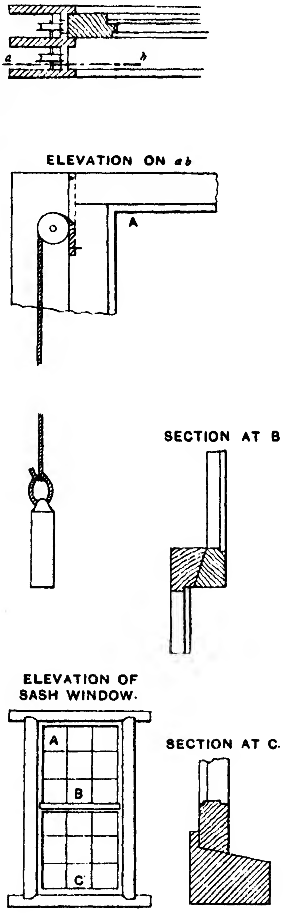

ENLARGED SECTION AT X.
Putty
Glass 12"×10"
X
X
7'
1'8"
12"
11"

Fig. 58.


ELEVATION ON a b
A
SECTION AT B
ELEVATION OF SASH WINDOW.
A
B
C
SECTION AT C.

CENTRES.

Fig. 59.

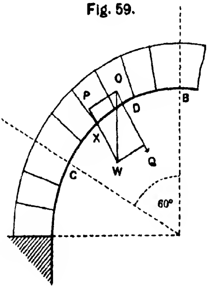


Fig. 60.

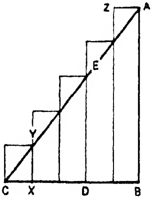


Fig. 61.

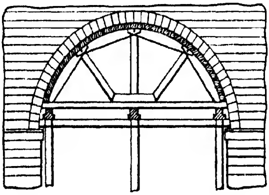
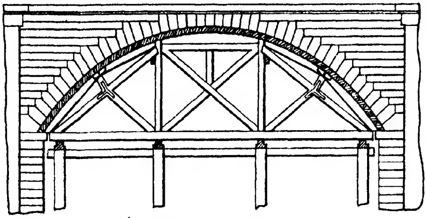


Fig. 62.

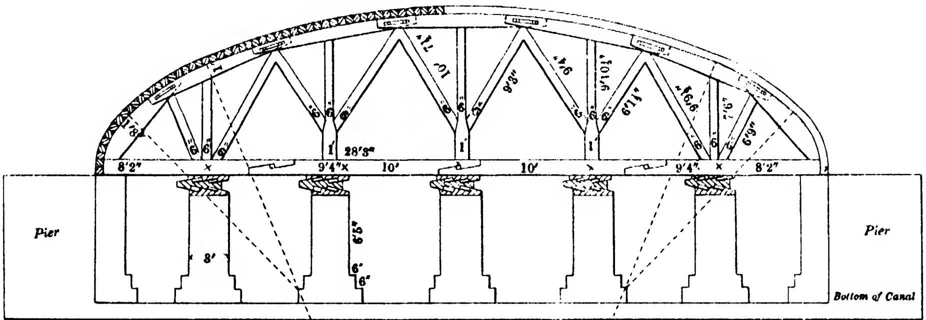


Scale—1 Inch = 18 Feet.

10 5 0 10 20 30 *feet.*

GANGES CANAL CENTRES.

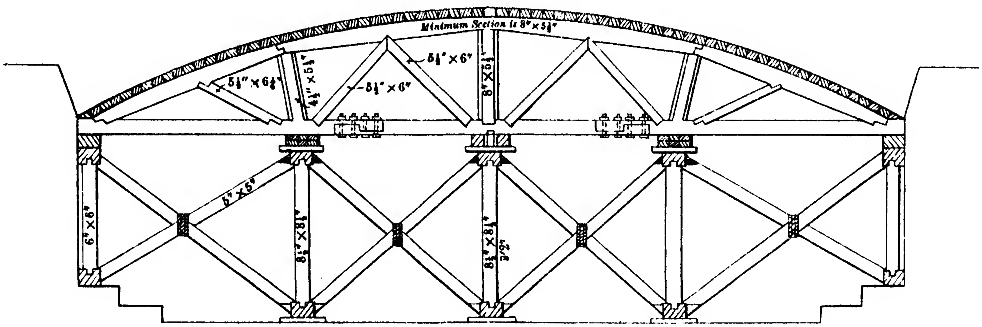
Fig. 63.



Scale—10 Feet = 1 Inch.

10 5 0 10 20 *feet.*

Fig. 64.

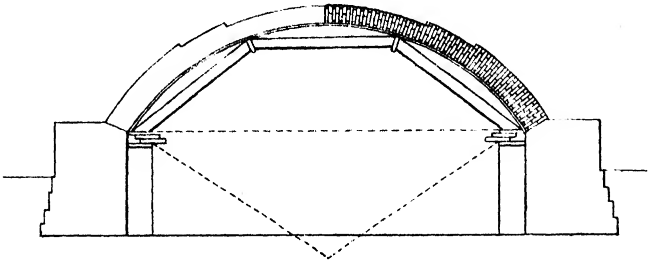


Scale—8 Feet = 1 Inch.

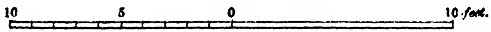
10 5 0 10 20 *feet.*

MADRAS CENTRES.

Fig. 65.



Scale—6 Feet = 1 Inch.



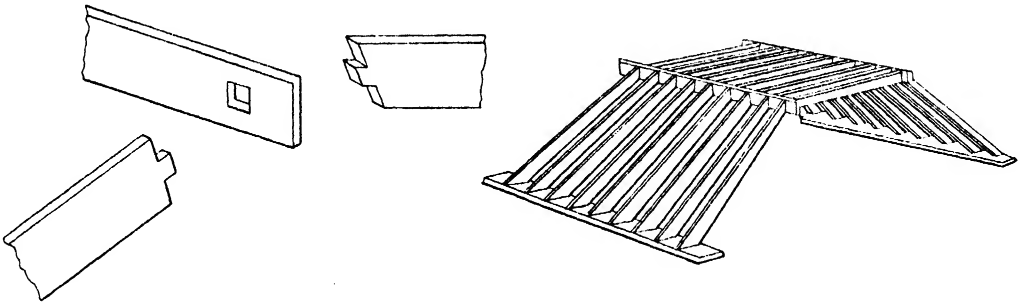


Fig 66.

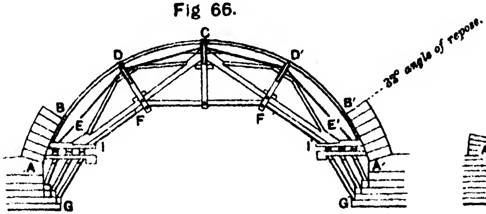
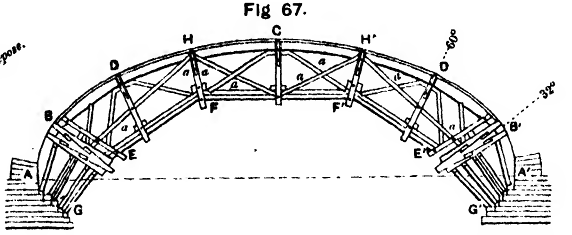
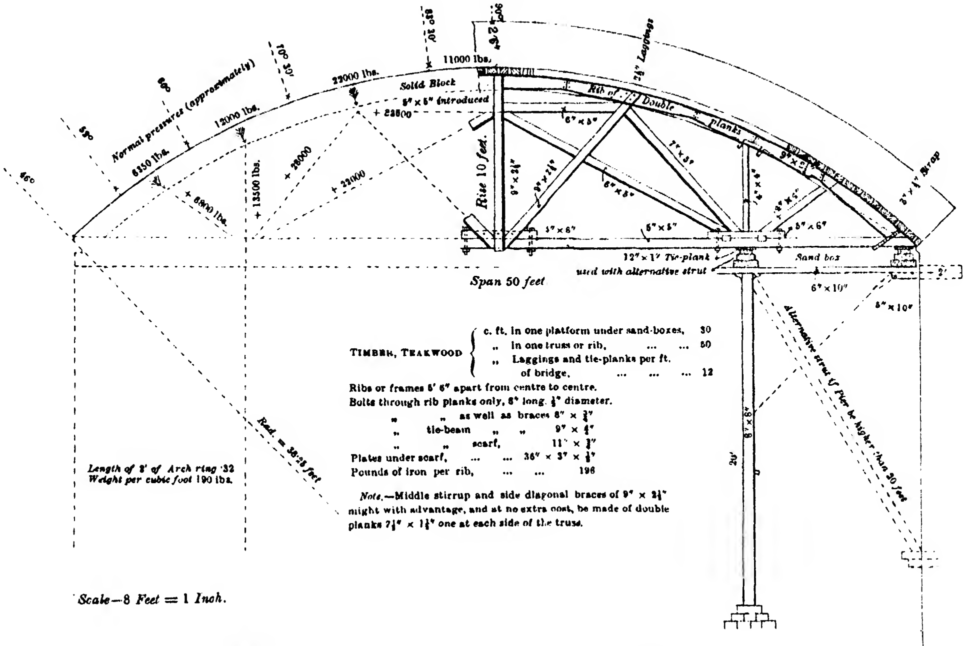


Fig 67.



WARDA BRIDGE CENTRES.

Fig. 68.



Scale—8 Feet = 1 Inch.

Fig. 69.

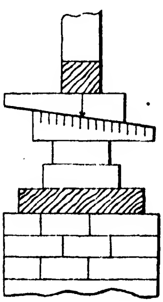


Fig. 70.

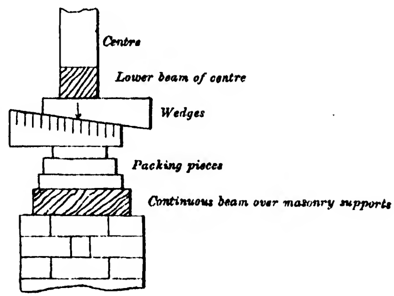
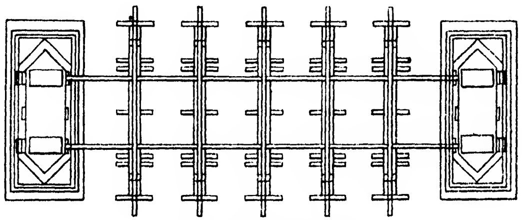


Fig. 71.

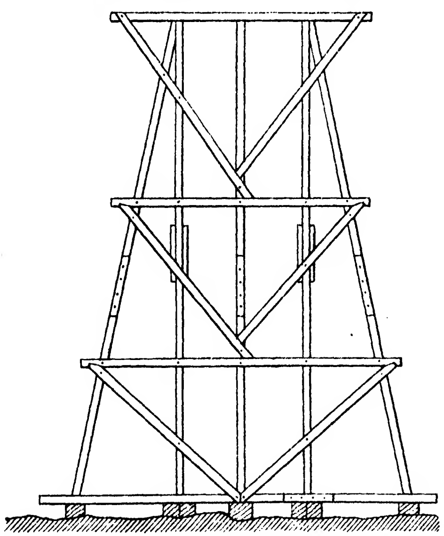
MAHANUDDY BRIDGE STAGING.

GENERAL PLAN OF STAGING OF ONE SPAN.

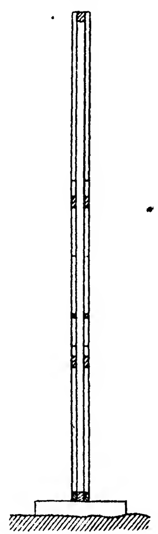


Scale--32 Feet to 1 Inch.

FRONT ELEVATION OF ONE TRESTLE.



CROSS SECTION.

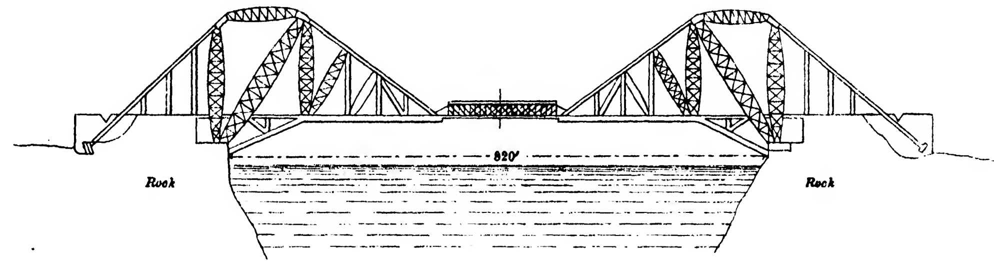


Scale--16 Feet to 1 Inch.

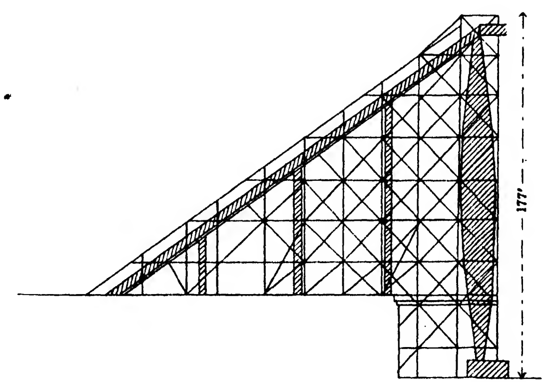
Fig. 72.

SUKKUR BRIDGE STAGING.

GENERAL ELEVATION OF BRIDGE.



SIDE ELEVATION OF STAGING.



ELEVATION FROM CENTRE OF RIVER.